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Implicit Learning of Complex Visual Contexts Under Non-Optimal Conditions

ABSTRACT

The human cognitive system is stunningly powerful in some respects yet surprisingly limited in others. We can recognize an object or a face in a single glimpse and type 70 words per minute, yet we cannot hold more than a few objects at a time in visual working memory or split our attention to several locations. Attention and working memory impose major capacity limitations in cognitive processing. This ARO funded project examines the role of implicit learning in overcoming cognitive limitations. It hinges on the observation that humans process a visual display more quickly when it is encountered for a second time. The project addresses three fundamental properties about spatial learning. First, does learning have a capacity limit? Second, is learning reduced when attention is tied up by a secondary load? Third, how much does the learning ability vary across individuals, and what are the cognitive and brain mechanisms that separate good learners from poor learners? We found that spatial context learning is automatic, flexible, has high capacity, and applies to most individuals. This mechanism can potentially overcome cognitive limitations in human attention and working memory, and may assist soldiers in spatial navigation.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

1. Jiang Y, Song J-H (2005). Spatial context learning in visual search and change detection. Perception & Psychophysics, 67(7), 1128-1139.

2. Jiang Y, Song J-H (2005). Hyper-specificity in visual implicit learning: Learning of spatial layout is contingent on item identity. Journal of Experimental Psychology: Human Perception & Performance, 31(6), 1439-1448.

3. Jiang Y, Song J-H, Rigas A (2005). High-capacity spatial contextual memory. Psychonomic Bulletin & Review, 12(3), 524-529.

4. Vickery TJ, King L-W, Jiang Y (2005). Setting up the target template in visual search. Journal of Vision, 5(1), 81-92.

5. Makovski T, Shim WM, Jiang YV (2006). Interference from filled delays on visual change detection. Journal of Vision, 6, 1459-1470.

6. Shen YJ, Jiang YV (2006). Interrupted visual searches reveal volatile search memory. Journal of Experimental Psychology: Human Perception &Performance, 32,1208-1220.

7. Makovski T., & Jiang YV (in press). Distributing versus focusing attention in visual short-term memory. Psychonomic Bulletin & Review.

8. Rausei V, Makovski T, & Jiang YV (in press). Attention dependency in implicit learning of repeated search context. Quarterly Journal of Experimental Psychology.

9. Jiang YV, Makovski T, Shim WM (to appear). Memory for features, conjunctions, objects, and locations. In J.R. Brockmole (Ed.), Memory for the visual world. Psychological Press.

Number of Papers published in peer-reviewed journals: 9.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

1. Matthews, C., Eng, H., Vickery, T., Shim, W.M., & Jiang, Y. (2006). Learning of arbitrary visual associations by trial-and-error. [Abstract]. [Journal of Vision, 6(6), 843a].

2. Vickery, T.J., Sussman, R.S., & Jiang, Y. (2006). Selective attention and general attentional resources in the learning of spatial context. [Abstract]. [Journal of Vision, 6(6), 844].

3. Shim, W.M., Alvarez, G.A., Vickery, T.J., & Jiang, Y. (2006). Effects of spatial and non-spatial attentional load on posterior parietal cortex. [Abstract]. [Journal of Vision, 6(6), 518].

4. King, L.W., Shim, W.M., & Jiang, Y. (2005). Implicit and explicit memory in scene-based contextual cueing. [Abstract]. [Journal of Vision, 5(8), 415].

5. Shen, Y., King, L.W., & Jiang, Y. (2005). Failed change detection produces volatile short-term memory. [Abstract]. [Journal of Vision, 5(8), 551].

6. Sussman, R.S., & Jiang, Y. (2005). Short and long term learning in visual search: An unexpected interference. [abstract]. [Journal of Vision, 5(8), 408].

7. Chen, D.Y., & Jiang, Y.V. (2007). Culture and spatial context learning. [Oral presentation presented at 2007 Vision Sciences Society meeting.

Number of Presentations: 7.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Jiang YV, King LW, Shim WM, Vickery TJ (2006). Visual implicit learning overcomes limits in human attention. Proceedings in 25th Army Science Conference.

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(d) Manuscripts

1. Vickery TJ, Sussman R, Jiang YV (submitted, under revision). Spatial context learning survives interference from working memory load.

2. Makovski T, Sussman R, Jiang YV (submitted). Orienting attention in visual working memory reduces interference from memory probes.

3. Jiang YV, Shim WM, Makovski T (submitted). Dissecting effects of object complexity from object similarity on visual working memory.

Number of Manuscripts: 3.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Timothy Vickery	0.01
Diyu Chen	0.25
Igor Bascandziev	0.01
Rachel Sussman	0.01
Maryam Vaziri Pashkam	0.01
Rama Chakravarthi	0.01
FTE Equivalent:	**0.30**
Total Number:	**6**

Names of Post Doctorates

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Won Mok Shim	0.01
FTE Equivalent:	**0.26**
Total Number:	**2**

Names of Faculty Supported

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FTE Equivalent:	**0.25**	
Total Number:	**1**	

Names of Under Graduate students supported

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Long Ouyang	0.01
Yankun Shen	0.01
Catherine Matthews	0.01
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Total Number:	**3**

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 2.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 2.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

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Names of Personnel receiving masters degrees

NAME	
Rachel Sussman	
Timothy Vickery	
Total Number:	**2**

Names of personnel receiving PHDs

NAME	
Joo-Hyun Song	
Total Number:	**1**

Names of other research staff

NAME	PERCENT_SUPPORTED	
Josh Hartshorne	0.10	No
Livia King	0.25	No
FTE Equivalent:	**0.35**	
Total Number:	**2**	

Sub Contractors (DD882)

Inventions (DD882)

Implicit Learning of Complex Visual Contexts Under Non-Optimal Conditions

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1. *Foreword*

This three-year project funded by the Army Research Office aims to explore cognitive mechanisms that allow us to overcome limitations in attention and working memory. It focuses on implicit learning of repeated spatial context. The results are promising in showing that this kind of learning occurs even when attention is directed elsewhere or when the spatial task is conducted under heavy secondary task load. The spatial context learning mechanism may potentially aid soldiers in spatial navigation.

2. *List of Appendix*

All published articles can be downloaded in their pdf format from the PI's laboratory webpage at: http://jianglab.psych.umn.edu. Requests for reprints can be sent to Y.V.Jiang: jiang166@umn.edu.

3. *Statement of the problem studied*

Humans process a visual display more efficiently when they encounter it for a second time. In visual search, for example, observers are faster at detecting a target when the same search display is occasionally repeated, even though they are unaware of the repetition. Such learning is implicit, existing without observers' conscious awareness. The project supported by the Army Research Office aims to address three fundamental properties about spatial context learning. (1) Does learning have a capacity limit? (2) Is it reduced when attention is tied up by a secondary task? (3) How much does the learning ability vary across individuals, and what are the cognitive and brain mechanisms that separate good learners from poor learners? In a series of 9 published studies and other conference reports, we found that spatial context learning is automatic, flexible, has high capacity, and applies to most individuals. This mechanism can potentially overcome cognitive limitations in human attention and working memory, and may assist soldiers in spatial navigation.

4. *Summary of the most important results*

(1) Visual implicit learning: Guidance of attention by learning

Humans process a visual display more efficiently when they encounter it for a second time. A previously perceived object, now presented briefly, is correctly identified more accurately than a new object, showing priming (Tulving & Schacter, 1990). Such perceptual facilitation is seen not only for isolated shapes or words, but also for complex visual displays (Chun & Jiang, 1998, 1999). When conducting visual search for a T target among L distractors, observers are faster at detecting the target when the same display is occasionally repeated (Chun & Jiang, 1998; Y. Jiang & J. H. Song, 2005; Y. H. Jiang & J. H. Song, 2005), even when observers are unaware of such repetition (Chun & Jiang, 2003). Implicit learning of repeated visual display allows attention to be deployed to target regions

defined by past experience. Such contextual learning is fast, with an effect appearing after only five or six repetitions; it is strong, preserved even when only half of the items are repeated (Song & Jiang, 2005); it is powerful, allowing at least 60 repeated displays to be learned (Y. H. Jiang, Song, & Rigas, 2005); and it is robust, persisting for at least a week (Chun & Jiang, 2003; Y. H. Jiang et al., 2005). It may compensate for our limitations in moment-to-moment attentional capacity.

(2) Attention and implicit learning

The role of attention in perception and memory is one of the longest standing debates in human cognition. Extensive evidence suggests that conscious perception and explicit memory depend on attention: Unattended information is often not perceived or remembered. But does implicit learning of complex visual displays depend on attention? To address this issue, we tested observers in a visual search task where they searched for a white T among black and white Ls. When the locations of the target and the attended set (white Ls) were repeated, search speed was enhanced; but when the locations of the target and the ignored set (black Ls) were repeated, search speed was unaffected. This suggests that the expression of learning depends on attention (Y. H. Jiang & Chun, 2001). However, during a transfer test, when the previously ignored set now was attended, it immediately facilitated performance. In contrast, when the previously attended set now was ignored, it no longer enhanced search speed (Y. H. Jiang & Leung, 2005). Thus, the expression of visual implicit learning depends on attention but latent learning of repeated information does not.

How much attention is needed for implicit learning to be expressed in behavior? Previous studies have found inconsistent results, with some implicit learning tasks requiring virtually no attention while others rely on attention. In one study we examined the degree of attentional dependency in implicit learning of repeated visual search context (Rausei, Makovski, & Jiang, in press). Observers searched for a target among distractors that were either highly similar to the target or dissimilar to the target. We found that the size of learning was comparable from repetition of the two types of distractors, even though attention dwelled much longer on distractors highly similar to the target. We suggest that beyond a minimal amount, further increase in attentional dwell time does not contribute significantly to implicit learning of repeated search context.

(3) Spatial context learning under heavy attentional load

Images of natural scenes are staggeringly complex, and in many respects our ability to extract and remember visual details is extremely limited (Rensink, 2002; Simons & Levin, 1998). Nevertheless, humans are capable of coping with this computational difficulty in the real world and navigate their surroundings without major problems. Two mechanisms are essential to overcoming the complexity of visual input: Implicit learning and visual attention. Is implicit learning reduced or eliminated by secondary tasks that load up attention? To find out, we tested observers in a dual-task condition where they divided attention between spatial context learning and a secondary task that heavily loaded up visual working memory. Our results found that divided attention does not significantly weaken spatial context learning (Vickery, Sussman, & Jiang, submitted). Spatial context learning was observed independent of whether learning was carried out as a single task or under heavy, secondary load tasks. These results show that learning of repeated visual context is relatively insensitive to attention. They support the general theoretical framework that divides explicit from implicit processes, with the latter being more robust to many stressors, including the availability of attention and working memory resources (Reber, 1989).

(4) Individual differences in spatial context learning

Given its potential importance in vision, spatial context learning may be a mechanism that every individual within the normal population is capable of. In fact, the degree of individual differences is generally narrower for implicit processes than explicit processes. Yet in our own research we often failed to see learning in a small subset of participants, approximately 20%, see also (Lleras & Von Muhlenen, 2004). Such variability is puzzling given that implicit learning is considered a stable ability across a variety of population groups. To study individual differences, we tested another group of individuals on spatial context learning and other tasks and correlated the size of learning with other abilities of the individual. Our results failed to show significant correlations between spatial context learning and performance in other tasks, such as mental rotation and visual working memory (Y. V. Jiang, King, Shim, & Vickery, 2006). In another study, we tested a group of individuals on spatial context learning across five sessions. We measured the size of learning in each session for each individual and rank ordered an individual's placement in the group for each session. The rank order was highly inconsistent: Individuals who ranked high in one session did not necessarily rank high in another session. The correlation across sessions was not significantly different from zero (Y. H. Jiang et al., 2005). An individual who does not show learning in one testing session is not necessarily someone who cannot learn from repeated spatial context. If tested again, that individual may show as much learning as other participants do. Indeed, a person who fails to show learning in one session may nonetheless show it a week later, even when no new training session was involved (Y. H. Jiang et al., 2005). Thus, the potential to learn from repeated spatial context most likely exists in every normal adult, but whether learning is revealed in a given testing session may depend on other experimental factors, such as the mode of attention, task difficulty, and display complexity.

(5) Brain mechanisms for spatial context learning

What is the neural basis of spatial context learning? To address this question, we used functional Magnetic Resonance Imaging (fMRI) to scan normal adults in a spatial context-learning task. On each trial observers viewed a circular array of 16 elements, one of which was a letter T rotated to the left or to the right. The elements were presented against a natural scene background. In the *old* condition, the background scene was repeated across blocks and the target T was always in the same position against the scene. In the *new* condition, neither the background scene nor the target location was repeated. Finally, in the *shuffled* condition, the background scene was repeatedly presented, but the target location could be at any of the 16 locations randomly determined. By comparing the three conditions, it was possible to separate associative learning from scene familiarity (Y. V. Jiang et al., 2006). Brain imaging data showed that parahippocampal place area and superior parietal lobule were both more active when participants searched from novel displays than from repeated, old displays. Furthermore, the parahippocampal place area was affected primarily by perceptual familiarity, but not by associative learning, as its activity was higher in the *new* condition than the *old* or *shuffled* conditions, but equally low in the latter two conditions. In contrast, the superior parietal lobule showed reduced activation in the *old* condition compared with the other conditions, suggesting that this brain region was sensitive to associative learning but not to perceptual familiarity. This study is one of the first to use neuroimaging to study spatial context learning. In combination with individual difference studies, this study can potentially assist the selection of soldiers, enhance the design of human-machine interface, and aid the selection of suitable aircraft or security personnel.

(6) Learning from interrupted visual searches

Imagine that a soldier is driving down a road, searching for a particular street, when suddenly a boy runs in front of his car and causes him to slam on the brakes. After the incident, he resumes his search for the street, but would he be able to use memory from his initial search attempt to aid search on resumption? Previous studies on visual search have not addressed this question directly, nor have they provided a conclusive answer. In a recent study, we investigated the nature of memory from ongoing but interrupted searches and its availability for search on resumption (Shen & Jiang, 2006). Participants conducted a change detection search task on polygons overlaid on scenes. Search was interrupted by various disruptions, including unfilled delay, passive viewing of other scenes, and additional search on new displays. Results showed that performance was unaffected by short intervals of unfilled delay or passive viewing, but it was impaired by additional search tasks. Across delays, memory for the spatial layout of the polygons was retained for future use, but memory for polygon shapes, background scenes, and absolute item location was not. We suggest that spatial memory aids interrupted visual searches, but the use of this memory is easily disrupted by additional searches.

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